> **PRO LEAGUES Target Solar for Stadiums** *page 14*

SOLAR TODAY®

LEADING THE RENEWABLE ENERGY REVOLUTION

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Architect Corey Saft adapts Germany's rigorous energy-efficiency standard to the steamy South.

Passivhaus Design, Louisiana Style

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FRED REARDON, WHIRLWIND SOLAR

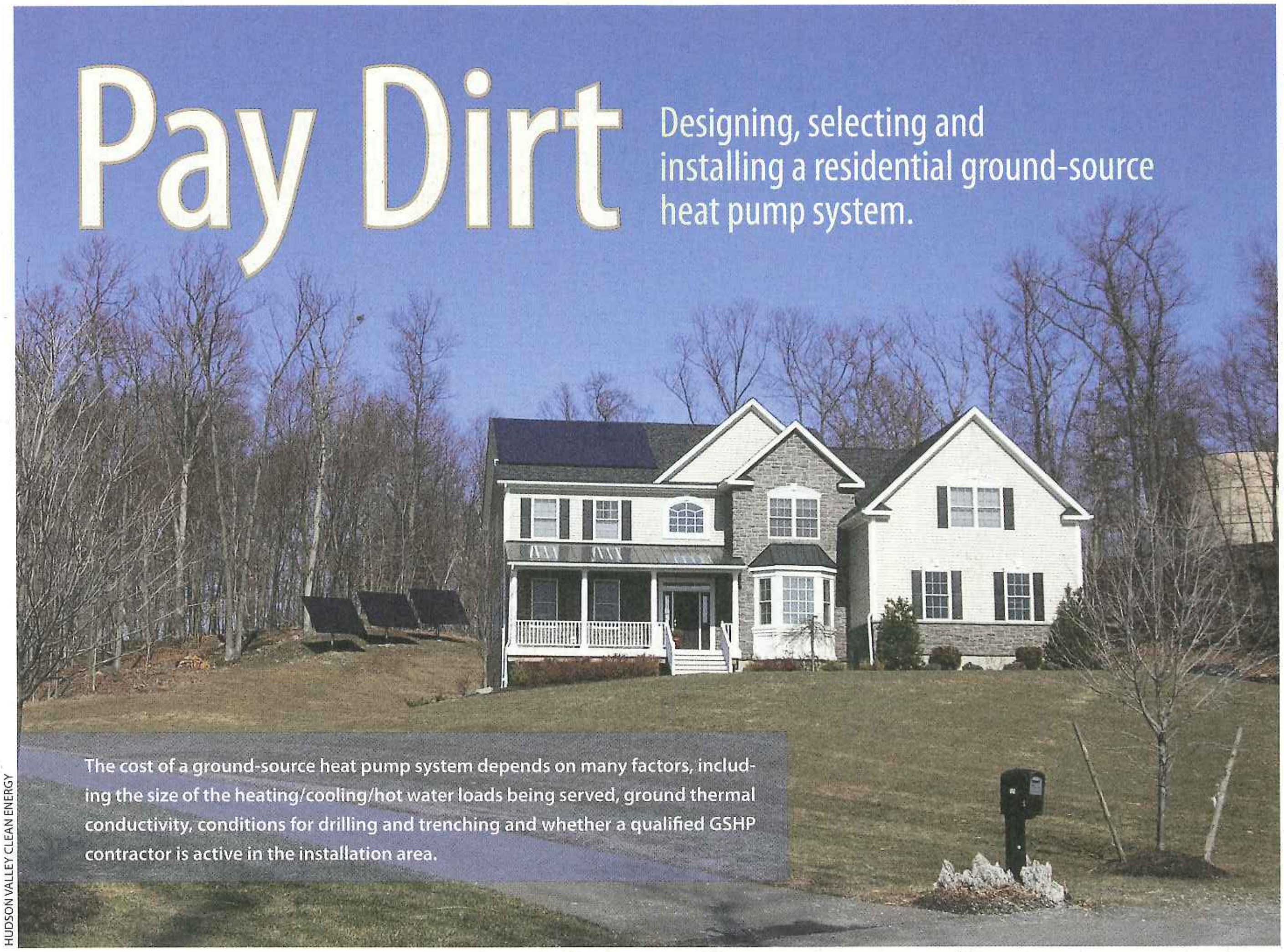

HUDSON VALLEY CLEAN ENERGY

ON THE COVER: Though the Passivhaus strategy is custom-fit for cold climates, architect Corey Saft, with Katrin Klingenberg of the Passive House Institute US, modified it for hot, humid Lafayette, La. The result is the South's first certified Passive House (as it is spelled in the United States). PHOTO BY ROBIN L. MAY

Articles appearing in this magazine are indexed in Environmental Periodicals Bibliography and ArchiText Construction Index: afsonl.com.

Next Issue: Building a Solar Movement

Initiated four years ago as a kitchen-table discussion about how to bring solar to a Washington, D.C., neighborhood, the Mt. Pleasant Solar Cooperative recently installed its 100th photovoltaic system. About one in 10 of this inner-city neighborhood's single-family homes now generate pollution-free solar energy, and the group has midwifed sister co-ops in six other D.C. neighborhoods. Co-op leaders share how interested consumers have become a movement.



The cost of a ground-source heat pump system depends on many factors, including the size of the heating/cooling/hot water loads being served, ground thermal conductivity, conditions for drilling and trenching and whether a qualified GSHP contractor is active in the installation area.

HUDSON VALLEY CLEAN ENERGY

Pay Dirt

Designing, selecting and installing a residential ground-source heat pump system.

By **XIAOBING LIU, PATRICK HUGHES** and **JEFF MUNK**

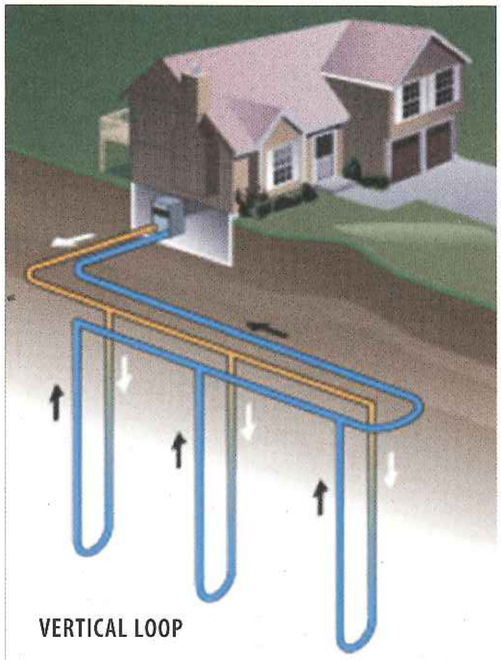
It's a compelling proposition: Use the near-constant-temperature heat underground to heat and cool your home and heat domestic water, slashing your energy bills. Yet despite studies demonstrating significant energy savings from ground-source heat pump (GSHP) systems, their adoption has been hindered by high upfront costs. Fewer than 1 percent of U.S. homes use a GSHP system. However, compared to a minimum-code-compliant conventional space-conditioning system, when properly designed and installed, a GSHP retrofit at current market prices offers simple payback of 4.3 years on national average, considering existing federal tax credits.

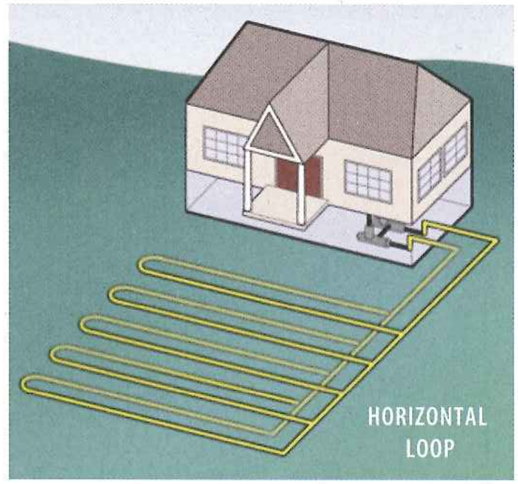
Most people understand how air-source heat pumps work: They move heat from indoor air to outdoor air when cooling and from outdoor air to indoor air when heating. The ground-source heat pump operates on the same principle, except that it moves heat to or from the ground source instead of outdoor air. The ground source is usually a vertical or horizontal ground heat exchanger (see the figures on page 35). Because the ground usually has a more favorable temperature than ambient air for the heating and cooling operation of the vapor-compression refrigeration cycle, GSHP systems can operate with much higher energy efficiencies than air-source heat pump systems when properly designed and installed.

A GSHP system used in a residential building typically provides space conditioning and hot water and comprises three major components: a water-source heat pump unit designed to operate at a wider range of entering fluid temperatures (typically from 30°F to 110°F, or 1°C to 43°C) than a conventional water-source heat pump unit; a ground heat exchanger (GHX); and distribution systems to deliver hot water to the storage tank and heating or cooling to the conditioned rooms. In most residential GSHP systems, the circulation pumps and associated valves are integrated with the heat pump to circulate the heat-carrier fluid (water or aqueous antifreeze solution) through the heat pump and the GHX.

A recent assessment indicates that if 20 percent of U.S. homes replaced their existing space-conditioning and water-heating systems with properly designed, installed and operated state-of-the-art GSHP systems, it would yield significant benefits each year. These include 0.8 quad British thermal units (Btu) of primary energy savings, 54.3 million metric tons of CO_2 emission reductions, $10.4 billion in energy cost savings and 43.2 gigawatts of reduction in summer peak electrical demand. (See Liu, X. 2010. "Assessment of National Benefits from Retrofitting Existing Single-Family Homes with Ground Source Heat Pump Systems." ORNL/TM-2010/122. Oak Ridge, Tenn.: Oak Ridge National Laboratory.)

VERTICAL AND HORIZONTAL GROUND HEAT EXCHANGERS





Evaluating the Economics

The cost of a GSHP system depends on many factors, including, but not limited to, the size of the heating/cooling/hot water loads being served, ground thermal conductivity, conditions for drilling and trenching and whether a qualified GSHP contractor is active in the installation area. It thus varies widely at different places and/or for different buildings.

A national survey of the cost of purchasing and installing GSHP systems reported that the average cost of a 3-ton residential GSHP system with vertical ground loop (including the ground loop, heat pump, ductwork, all other components and labors associated with the installation) was $8,997 in 1995 U.S. dollars. (See Kavanaugh, S., C. Gilbreath, and J. Kilpatrick. 1995. "Cost Containment for Ground-Source Heat Pumps, Final Report." Tuscaloosa, Ala.: University of Alabama.) Considering the average 2.47 percent annual inflation between 1995 and 2010 and improvements of water-source heat pump units, a state-of-the-art GSHP today costs $15,748 in 2010 dollars (before federal and local incentives). Should the GSHP system be massively deployed, with current technologies, the report estimated that the total cost of a residential GSHP system can be reduced by 19 percent (Kavanaugh 1995).

A comparison of retrofit costs for the 3-ton state-of-the-art GSHP system and two alternative space-conditioning systems are presented in 2010 dollars in table 1 (at left). The first alternative (Alt #1) is a new, minimum-code-compliant, conventional space-conditioning system with a SEER (seasonal energy efficiency ratio) 13 air conditioner and 80 AFUE (annual fuel utilization efficiency) gas furnace. The second alternative (Alt #2) is a new, state-of-the-art, conventional space-conditioning system with a SEER 21 air conditioner and 93 AFUE gas furnace. As shown in table 1, without any federal and local incentives, the national average comparable cost of retrofitting an existing 3-ton space-conditioning system with the state-of-the-art GSHP system is more than double the cost ($11,241 vs. $4,500) of Alt #1. However, if the estimated 19 percent cost-reduction potential forecast by Kavanaugh et al., is fully realized, the cost of the GSHP retrofit will be reduced to $9,102. Though it is still about double the

TABLE 1. **Comparing Costs of a 3-Ton Ground-Source Heat Pump (GSHP) and Alternative Systems**

System	Itemized Cost	Average Market Price	Reduced Price*
State-of-the-Art GSHP	Ground loop	$4,330	$3,823
	Heat pump (include pump)	$6,911	$5,279
	Indoor installation	$2,671	$1,911
	Ductwork	$1,836	$1,836
	Total Installed Retrofit Cost	$15,748	$12,849
	Comparable Cost (without indoor installation and ductwork)	$11,241	$9,102
	Itemized Cost	Alternative #1 SEER 13 AC and 80 AFUE gas furnace	Alternative #2 SEER 21 AC and 93 AFUE gas furnace
Alternatives	AC unit	$2,500	$5,142
	Gas furnace	$2,000	$3,500
	Indoor installation	$2,671	$1,911
	Ductwork	$1,836	$1,836
	Total Installed Retrofit Cost	$9,007	$12,389
	Comparable Cost (without indoor installation and ductwork)	$4,500	$8,642

* Researchers estimate that economies of scale resulting from massive deployment can reduce the total cost of a residential GSHP system by 19 percent. Kavanaugh, S., C. Gilbreath, and J. Kilpatrick. 1995. "Cost Containment for Ground-Source Heat Pumps, Final Report." Tuscaloosa, Ala.: University of Alabama.

cost for Alt #1, it is close to the cost of Alt #2 ($9,102 vs. $8,642). With currently enacted federal tax credits, which offset 30 percent of the installed cost of GSHP systems (valid through 2016), the cost premium of GSHP system can be further reduced.

Table 2 (at right) summarizes the national average annual energy expenditures for the 3-ton state-of-the-art GSHP system and the two alternatives in a typical single-family home. As indicated, on national average, the state-of-the-art GSHP system saves $469 and $332 each year compared with Alt #1 and Alt #2, respectively.

Compared with Alt #1, on national average, the simple payback period of the GSHP retrofit at current market prices is 14.4 years. It falls to 9.8 years if the 19 percent cost-reduction potential is fully realized. Even without cost reduction, the simple payback falls to 4.3 years if the 30 percent federal tax credit is accounted for. The simple payback period for the GSHP retrofit becomes much shorter when compared with the state-of-the-art conventional system (Alt #2). With the 19 percent cost reduction, the simple payback period of the GSHP retrofit is only 2.4 years. When compared with Alt #2, investments in the GSHP retrofit at current market prices show a positive net present value (NPV) over the typical 20-year service life of a heat pump, even when future energy cost savings are discounted at rates as high as 14 percent. However, when compared with Alt #1, investment in the GSHP retrofit at current market prices will yield a positive NPV only when the discount rate is lower than 8 percent. If the 19 percent cost-reduction potential of GSHP systems can be fully realized, investments in the GSHP retrofit will have positive NPVs even with higher discount rates. With the existing 30 percent federal tax credit, investments in GSHP retrofits are quite attractive across the board, assuming the homeowners are earning income and paying taxes.

TABLE 2. **Annual Energy Savings from a 3-Ton Ground-Source Heat Pump (GSHP) Retrofit vs. Alternatives**

	State-of-the-art GSHP system	Alternative #1	Alternative #2
National average of annual energy expenditure for space conditioning per single-family home	$709	$1,178	$1,040
National average of annual energy expenditure savings per single-family home from GSHP retrofit compared with alternative systems		$469	$332

Installing a ground-source heat pump begins with drilling a few small vertical bores a few hundred feet deep (for a vertical-loop heat exchanger), or digging a few 6- to 8-feet-deep trenches a few hundred feet long (for a horizontal-loop heat exchanger).

If 20 percent of U.S. homes replaced their space-conditioning and water-heating systems with state-of-the-art GSHP systems, it would yield significant benefits each year: 0.8 quad Btu of primary energy savings, 54.3 million metric tons of CO_2 emission reductions, $10.4 billion in energy cost savings and 43.2 gigawatts of reduction in summer peak electrical demand.

Designing a GSHP System

Designing a residential GSHP system involves calculating building heating and cooling loads, selecting the heat pumps and circulation pumps, determining the type and size of the GHX and designing a distribution system in the building. For highly energy-efficient homes with airtight walls, windows and roofs, the system must also include mechanical ventilation.

Calculating Building Loads. Building heating and cooling loads are the basis for selecting heat pumps and designing the GHX. To get a high-performance GSHP system, the building loads must be calculated accurately, both for the entire building and for each individual room. The room loads are used to determine the size of the distribution system for each room, and the building (block) load, which accounts for the diversity of the room loads at the heating and cooling design conditions, is used to size the heat pump.

Many factors affect the heating and cooling loads of a building, including the local weather, the building's construction type and quality,

Once the bores or trenches have been dug, workers insert HDPE or PEX-A pipes to serve as the ground heat exchanger.

On national average, a 3-ton state-of-the-art GSHP system saves $469 and $332 in annual energy costs over a combined SEER 13 air conditioner/80 AFUE gas furnace and SEER 21 air conditioner/93 AFUE gas furnace, respectively.

orientation, vintage and use (e.g., number of occupants and thermostat set points). The combined effects of these factors make building loads per unit of conditioned floor area vary widely for different buildings. It is thus necessary to calculate the heating and cooling loads of a particular building with a qualified procedure or software, such as the "Manual J: Residential Load Calculation" method and associated tools developed by the Air Conditioning Contractors of America (ACCA).

Selecting the Heat Pump. The heat pump unit should be sized based on the maximum building loads and any additional loads, such as heat gain/loss through the distribution system if it is exposed to unconditioned spaces and the loads for conditioning the outdoor ventilation air. Since the heat pump provides both space heating and cooling, both the maximum heating and cooling loads of the building must be considered when selecting a heat pump.

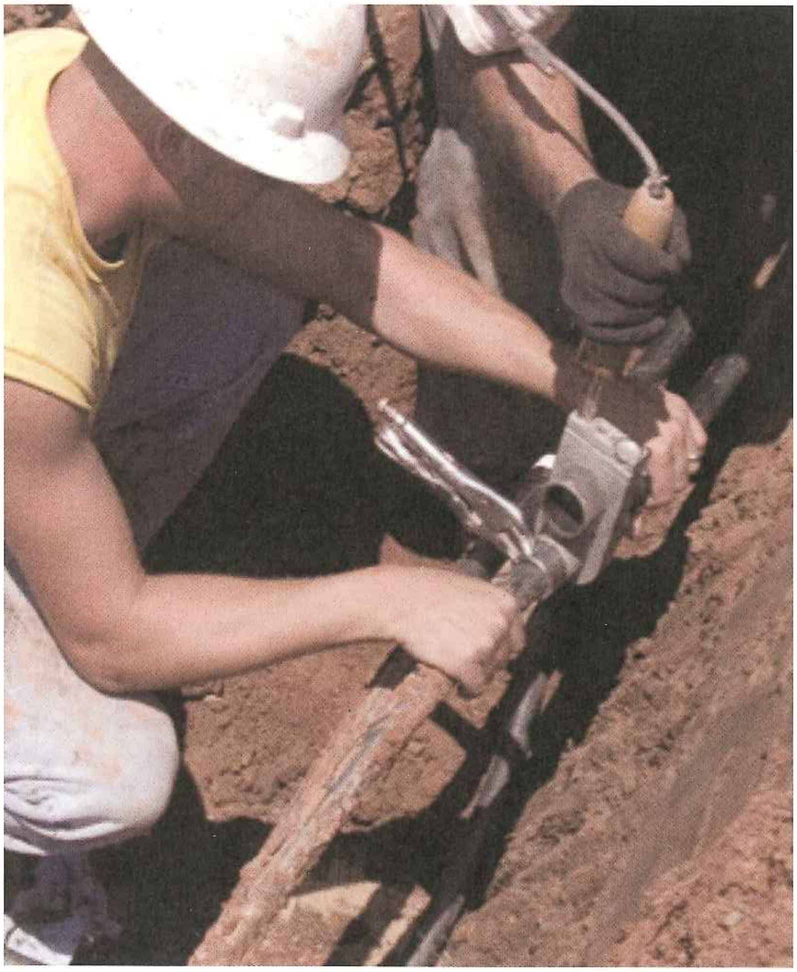
For buildings with much higher heating loads than cooling loads (in cold climates), experts recommend using a heat pump with staged or variable capacity and sizing the heat pump to satisfy the maximum heating load. Such units can run at low capacity during cooling operation and experience run times long enough to provide adequate dehumidification. If a single-capacity heat pump is used in a heating-dominant building, to achieve adequate dehumidification, the cooling capacity of the heat pump should not exceed the design total (sensible plus latent) cooling load by more than 25 percent. In this case, the heating capacity of the heat pump may be inadequate. For buildings with dominant cooling loads or balanced loads, the heat pump should be sized to satisfy both the sensible and latent parts of the design cooling load. An oversized heat pump will result in poor temperature and humidity control. On the other hand, an undersized heat pump will be unable to maintain desired temperatures without degrading the energy efficiency of the GSHP system through use of supplemental heat (e.g., electric resistance heat). ACCA's "Manual S: Residential Equipment Selection" provides further guidance on how to properly select a heat pump unit.

Packaged or split water-to-air heat pumps with cooling capacity from 2 to 5 tons are most common in residential GSHP systems in the United States. Small packaged water-to-water heat pumps are also sometimes used. Rather than directly delivering cold or hot air to conditioned spaces as the water-to-air heat pump does, a water-to-water heat pump delivers chilled or hot water to various types of terminals, such as radiant floors or ceilings or fan coil units.

After burying the ground heat exchanger pipes, installers grout the bores with bentonite or cement-based material.

Designing the Ground Heat Exchanger. The most popularly used GHX in GSHP systems in the United States is the ground-coupled, closed-loop heat exchanger using high-density polyethylene (HDPE) or cross-linked polyethylene (PEX-A) pipes buried in the earth in either a vertical or horizontal configuration. The closed-loop technology permits the GSHP system to be applied effectively in almost any location. There are three basic types of closed-loop GHX: vertical bore, horizontal trench and horizontal bore.

Available land area, installation cost (which depends on drill and trenching conditions), disturbances to existing land use and the capabilities of local installers are the most important determinants for selecting a GHX. The vertical-bore GHX



Here installers fuse the buried pipes and connect them to the heat pump either directly or through a header.

A 3-ton state-of-the-art GSHP today costs $15,748 (before federal and local incentives). Should the GSHP system be massively deployed, with current technologies, the total cost of a residential GSHP system can be reduced by an estimated 19 percent.

requires the least land area, and the horizontal-trench GHX requires the most land area. While the horizontal-bore GHX requires as much or more land area than the horizontal-trench GHX, it can be placed under existing structures without disturbing the surface area above the GHX.

A GHX is usually designed to maintain the entering fluid temperature of the heat pump within a favorable range, typically between 35°F and 95°F (2°C to 35°C), over 20–30 years. The International Ground Source Heat Pump Association's (IGSHPA's) "Ground Source Heat Pump Residential and Light Commercial Design and Installation Guide" provides specs. For a vertical-bore GHX, the bores are typically installed 15 to 25 feet (4.6 to 7.6 m) apart and the required linear length of the bores usually ranges from 150 to 250 feet (46 to 76 m) per nominal ton of heat pump capacity. For a horizontal-trench GHX, the trenches are commonly installed 10 feet (3 m) apart and the trench length is up to 150 feet per nominal ton of heat pump capacity. For the horizontal-bore GHX, which is installed with a horizontal boring machine at least 15 feet deep under the surface area, a minimum length of 225 feet (69 m) of horizontal bore is normally required per nominal ton of heat pump capacity. The actual size of a GHX is determined by many site-specific factors, including the heat rejection and extraction loads imposed on it (which can be calculated with building loads and heat pump efficiencies in cooling and heating operations), layout of the ground loops, soil and rock conditions and grouting/backfilling material thermal properties.

Several software programs are available to facilitate the design of the GHX in a residential GSHP system, such as GeoDesigner (climatemaster.com) and GLD (groundloopdesign.com).

Designing Distribution. In the United States, the most popular distribution system for residential space conditioning is a central forced-air system, which delivers a fixed amount of airflow to each zone. The distribution system can also use water as a heat carrier. In this case, terminal units such as fan coils or radiant floors are required to condition the room air. Because heat pumps usually cannot produce as high a temperature as gas-furnaces or boilers do, it is critical to design the terminal units in hydronic systems according to the peak heating demand and the available temperature of the heat-carrier fluid.

To reduce the energy consumption of a GSHP system, consider using a multi-zone distribution system coupled with a staged/variable-capacity heat pump. Unlike typical single-zone systems, which treat the entire home as one zone, multi-zone systems can condition different zones in the home independently. A multi-zone system typically employs electromechanical dampers or two-way/three-way valves to modulate the air or water flow to each zone, which has either a temperature sensor that feeds back to a central controller or a thermostat of its own. It allows temperatures in unoccupied zones to be set back while maintaining comfortable temperatures in occupied zones. To fully realize the energy-saving potential of a multi-zone system, the capacity of the heat pump should be variable to satisfy the building's fluctuating needs.

Ensuring Ventilation. As designers continue efforts to reduce energy needed for space conditioning, homes become more airtight and thus need mechanical ventilation to bring outdoor air inside to dilute or remove interior air odors and contaminants. As an energy-saving measure, an air-to-air heat-exchange device can be integrated into the return air duct of the heat pump or installed separately so that the heat or cool energy of the exhaust air can be recovered to pre-condition the outdoor ventilation air. The loads required for conditioning the outdoor ventilation air, with or without heat recovery, must be accounted for when sizing the heat pump.

Installing, Maintaining and Operating a GSHP System

The installation of a residential GSHP system can be divided into two parts: the installation within the building, including installation of all interior piping and ductwork, controls and so on, and the installation outside the building, including installation of the GHX, exterior piping, headers and other components. In most cases, the heat pump unit will be installed inside the building, such as in the basement or mechanical closet of the building.

The inside installation of a residential GSHP system is basically the same as that of a conventional forced-air or hydronic space-conditioning system. The installation of the outside part of a residential GSHP system is different, however. It involves the following tasks:

- Drill a few small vertical bores (with 4- to 6-inch diameter) a few hundred feet deep, or dig a few 5- to 6-foot-deep trenches a few hundred feet long.
- Put HDPE or PEX-A pipes into the bores or trenches.
- Grout the bores with bentonite or cement-based material, or backfill the trenches with the excavated soil.
- Join the pipes by heat fusion and connect them to the heat pump either directly or through a header.
- Conduct hydrostatic pressure tests to detect any water leakage and repair if necessary.
- Purge air and flush any debris out of the entire loop.

Click for More Information

Air Conditioning Contractors of America, for load calculation, equipment selection, design and installation guidance: **acca.org**

Geothermal Exchange Organization, the industry's trade association: **geoexchange.org**

International Ground Source Heat Pump Association, for design and installation guidance, training and a directory of certified professionals: **igshpa.okstate.edu**

Because almost all the components of a residential GSHP system are either buried in the earth or installed inside the building, they usually require less maintenance and have longer service life than conventional space-conditioning systems.

The IGSHPA's design and installation guide details the above tasks and the technical skill required to perform them. To ensure the quality of a GHX, which has to be assembled and installed at the job site, installers need to have the appropriate technical training and, more importantly, perform the installation using proper tools and materials following appropriate procedures. IGSHPA offers training classes for both installers and designers of GSHP systems. To help improve installation quality, ACCA is updating its "HVAC Quality Installation Specification" to include GSHP systems. In addition, as part of the American Reinvestment and Recovery Act, the Geothermal Exchange Organization (GEO, geoexchange.org) is working with IGSHPA and Oak Ridge National Laboratory to create the first national certification standard for professionals involved in the design, installation, operation and maintenance of GSHP systems.

Because almost all the components of a residential GSHP system are either buried in the earth or installed inside the building, they usually require less maintenance and have longer service life than conventional space-conditioning systems. The operation and control of a residential GSHP system is as simple as that of a typical central air-conditioning system. Because there is no need for defrosting, the operation and control of a residential GSHP system is actually simpler than for air-source heat pump systems. ST

Dr. Xiaobing Liu is a staff scientist at the Building Technologies Research and Integration Center (BTRIC) of Oak Ridge National Laboratory. He has provided technical assistance on the design of approximately 30 high-profile domestic and international projects, including ASHRAE headquarters, the Oklahoma Governor's Mansion, the Metro Complex building in Turkey and the Future House in China.

Patrick Hughes is the BTRIC director. His history with GSHP technology dates back to the late 1970s and includes such honors as a Department of Energy Award for Energy Innovation in 1987 for a ground-source heat pump project providing a "distinguished contribution to our Nation's energy efficiency" and IGSHPA's Outstanding Engineering Achievement Award in 1998.

Jeffrey Munk is the BTRIC staff scientist responsible for the experimental GSHP systems in the ZEBRAlliance (zebralliance.com) research houses.